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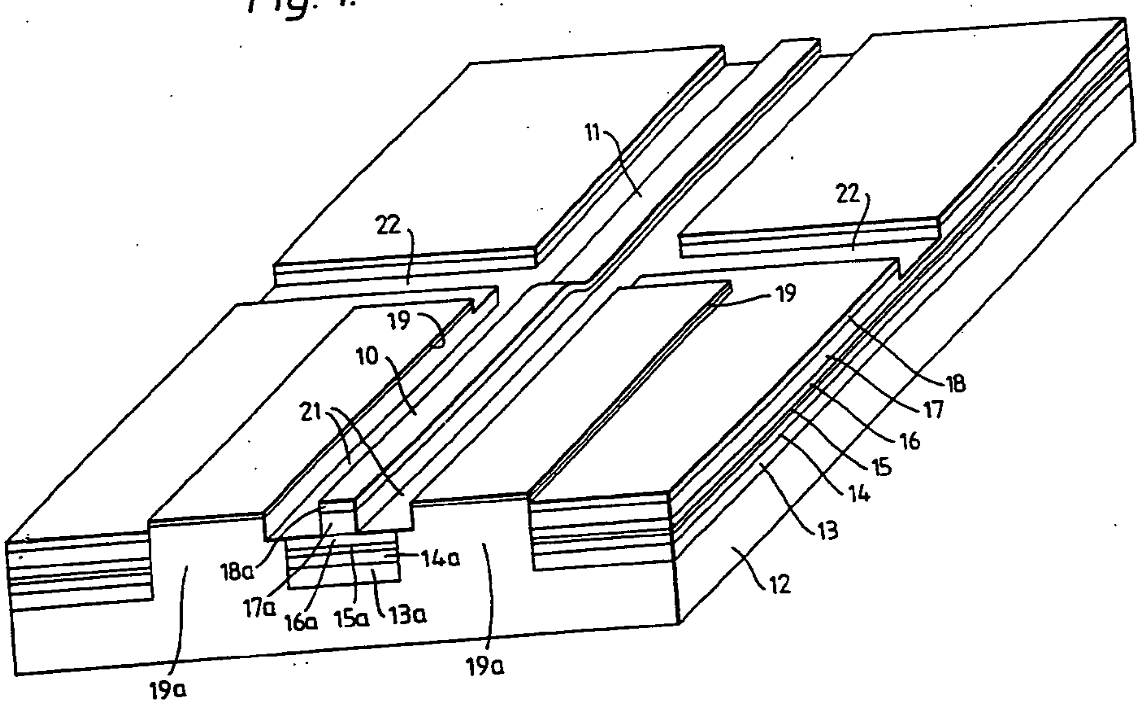
(54) **Semiconductor optical source**

(57) A monolithic semiconductor structure that includes a multi-quantum-well laser (10) and a quantum-confined Stark effect modulator (11) optionally in tandem. The quantum-well layers are grown under conditions providing an enhanced growth rate and thereby greater thickness in the region of the laser compared with that of the modulator thus providing a reduced attenuation of the laser emission by the modulator in its unbiased state.

Fig. 1.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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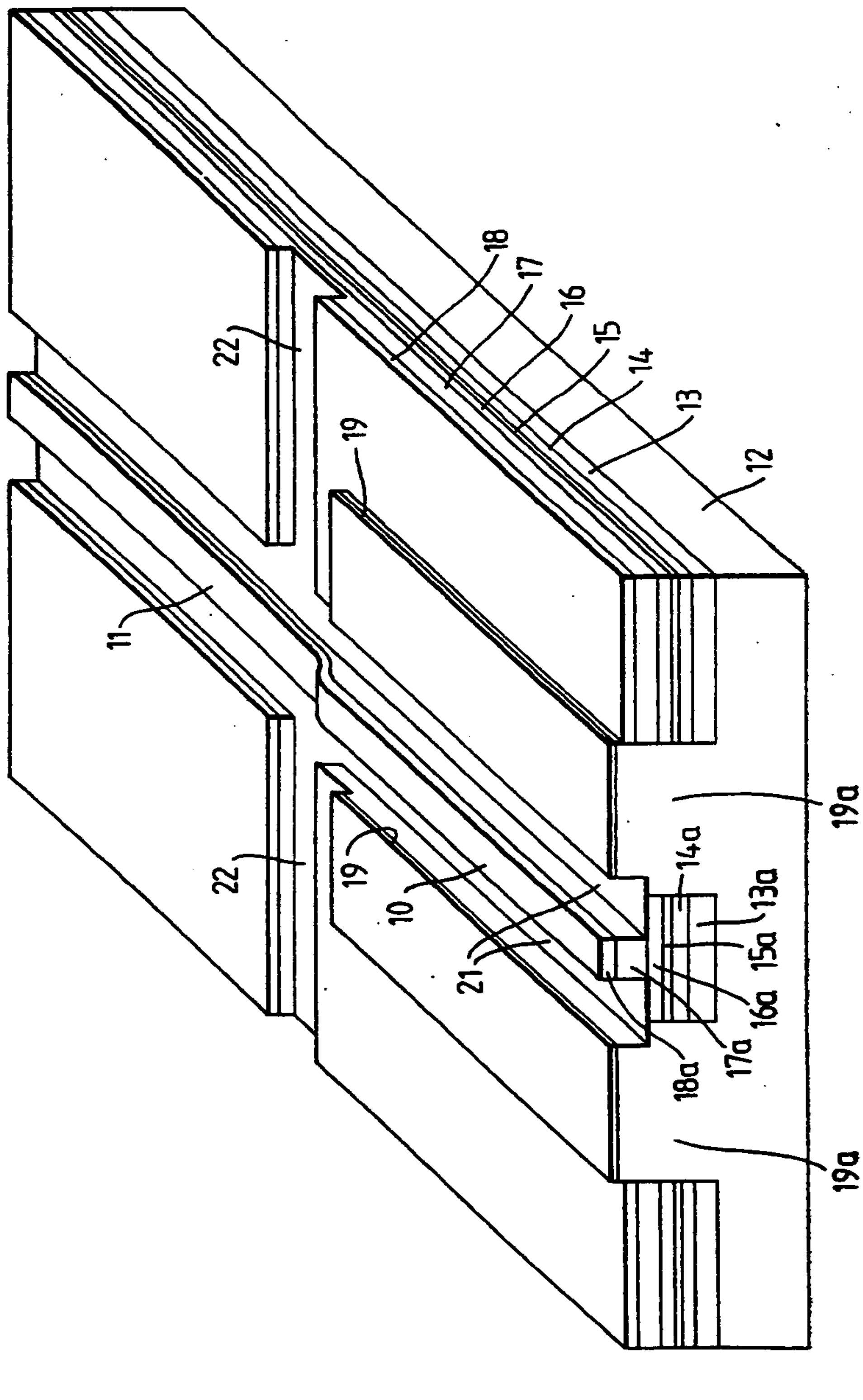
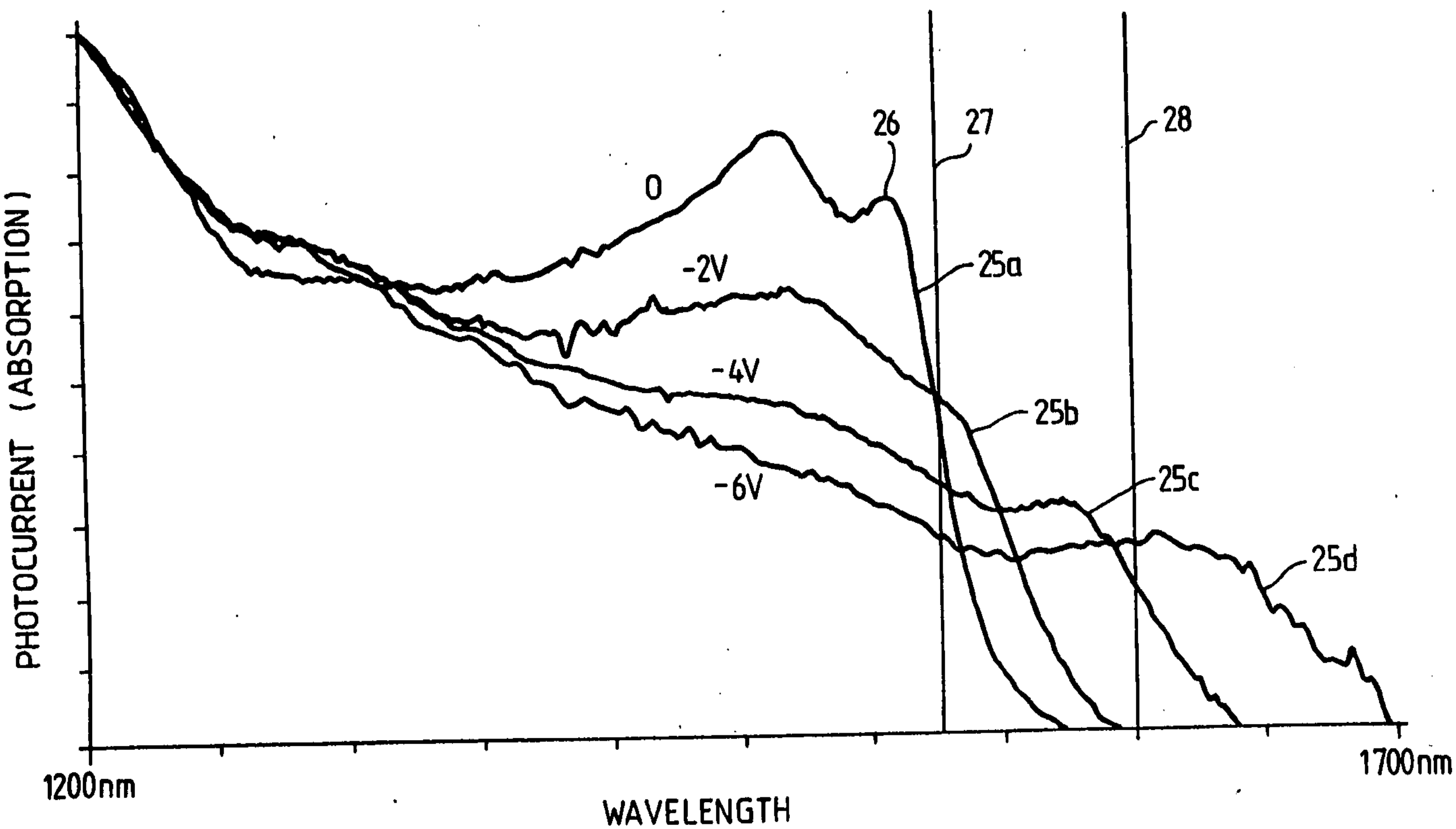


18
17
16
15
14
13
12
22
19
11
19a
14a
13a
15a
16a
17a
18a
21
10
19
22
19a

Fig. 1.

Fig. 2.



PHOTOCURRENT (ABSORPTION)
WAVELENGTH
1200nm
1700nm
0
-2V
-4V
-6V
26
27
28
25a
25b
25c
25d

Semiconductor Optical Source

This invention relates to semiconductor optical sources and in particular to low chirp coherent light sources.

One of the advantages of semiconductor optical sources for optical communications is that the light output of an LED or semiconductor laser can be directly modulated by modulation of its drive current. However, for certain applications, this advantage is completely negated by the fact that such direct modulation of the drive current produces an amplitude modulation of the light output which is accompanied by a frequency modulation expressing itself as 'chirp'. This invention is particularly concerned with the provision of an optical source in which low chirp is attained by having a semiconductor laser and modulator optically in tandem, and by arranging to modulate the modulator drive instead of the laser drive, the latter being maintained at a constant drive level. An example of such an approach is to be found in the paper by H. Soda et al entitled '5 Gbit/s Modulation Characteristics of Optical Intensity Modulator Monolithically Integrated with DFB Laser', Electronics Letters 2nd March 1989 Vol. 25 No. 5 pp 334-5. The modulator of that monolithic structure was a Franz-Keldysh effect modulator. The present invention is directed to monolithic structures with quantum confined Stark effect QCSE modulators. A

particular advantage of the use of a QCSE modulator is that it is capable of providing a modulation efficiency up to four times greater than that achievable with a Franz-Keldysh modulator.

According to the present invention there is provided a monolithic semiconductor structure that includes an injection laser and a quantum-confined Stark effect optical modulator optically in tandem.

Preferably the laser is a quantum-well laser, in which case one or more quantum well-layers of the laser may be continued to form quantum-well layers of the modulator. If the quantum-well layers of the laser and of the modulator are made of the same material, it is preferred to make some or all of the quantum-well layers of the laser thicker than corresponding layers of the modulator so that the fundamental exciton absorption peak of he unbiased modulator is further on the short wavelength side of the laser emission wavelength than it would be if all the quantum-well layers were of the same thickness in both the laser and the modulator.

Accordingly the invention further provides a monolithic semiconductor structure that includes a quantum-well laser and a quantum-confined Stark effect optical modulator optically in tandem, wherein the or each quantum-well layer of the laser is of greater thickness than the corresponding quantum-well layer of the modulator, so that when the modulator is unbiased, its fundamental exciton absorption peak is further on the short wavelength side of the laser emission wavelength than it would be if the quantum-well layers were the same thickness in both the laser and the modulator.

Additionally the invention provides a method of

making a monolithic semiconductor structure that includes a quantum-well laser and a quantum-confined Stark effect modulator optically in tandem, wherein the quantum-well layers of both the laser and the modulator are epitaxially grown simultaneously upon a substrate whose topography provides a faster growth rate, and hence greater layer thickness, in the region employed to form the laser than in the region employed to form the modulator so that, in the completed structure when the modulator is unbiased, its fundamental exciton absorption peak is further on the short wavelength side of the laser emission wavelength than it would be if the quantum-well layers had been grown with the same layer thickness in both the laser and the modulator.

There follows a description of examples of semiconductor monolithic modulator and laser structures embodying the invention in preferred forms. The description refers to the accompanying drawings in which:-

Figure 1 is a schematic perspective view of one chip of a two-dimensioned array of chips of a wafer, each chip comprising a tandem arrangement of laser and modulator, and

Figure 2 is a graph showing the spectral characteristics of a quantum-confined Stark effect modulator under different bias conditions.

Figure 1 depicts a schematic perspective view of one chip of a two-dimensional array of identical chips formed in a semiconductor wafer, the chip comprising a tandem arrangement of separate-confinement heterostructure multi-quantum-well laser 10 and quantum-confined Stark effect modulator 11 in which the quantum-well layers of the laser are grown at the same time as those of the modulator. Figure 1 depicts the

chip before the application of its contact masking layer and its two contact layers. The basic layer structure of the chip is similar to that of the multi-quantum-well laser described by R.W. Glew et al 'Very Low Threshold Current Density SCH-MQW Laser Diodes Emitting at 1.55 um', Electronics Letters 3rd August 1989 Vol. 25 No. 16 pp 1103-4, though in this instance feedback for the laser is provided by a distributed feedback configuration rather than by reflecting end facets.

The layer structure comprises an n-type InP substrate 12 upon which is epitaxially grown a n-type buffer (lower cladding) layer 13, an undoped AlGaInAs or InGaAsP lower waveguide layer 14, a four quantum well stack 15 comprising four GaInAs quantum-well layers (not separately depicted) interleaved with three AlGaInAs or InGaAsP barrier layers (not separately depicted), an undoped AlGaInAs or InGaAsP upper waveguide layer 16, a p-type InP upper cladding layer 17, and a p-type GaInAs capping layer 18.

The laser 10 is typically 200 to 300 µm long, and the modulator 11 is typically in the range 50 to 200 µm long. The chip is typically 200 to 300 µm wide. Prior to the deposition of the epitaxial layers 13 to 18, two masking stripes 19 of silica, each the length of the laser 10, having a width of about 40 µm and a separation of about 5 to 15 µm are deposited upon the substrate 12 which may be subsequently etched so that each step stands on a plinth 19a of substrate material. These two masking strips 19 provide areas where vapour phase epitaxial growth is inhibited and, as a result of that inhibition, growth is enhanced between the two stripes in comparison with growth that occurs in regions remote from those stripes. Thus, neglecting fringing effects (not illustrated), each of the epitaxially deposited layers 13 to 18 has a uniform thickness over

the whole area of the chip except for the region 13a to 18a lying between the two stripes where it is thicker. The purpose of providing the localised thickening is to provide quantum-well layers that are thicker in the region of the laser 10 than they are in the region of the modulator 11. The attendant thickening of the other epitaxially deposited layers is not deliberate, but is an incidental result of the chosen method used for thickening the quantum-well layers. The quantum-well layers have an aggregate thickness that is so small in comparison with the optical waveguide thickness defined by the distance separating the upper and lower cladding layers 17 and 13 that, if the localised thickness were confined to the quantum-well layers, the offset between the waveguide of the laser 10 and that of the modulator 11 would be much too small to be significant. The offset is however greater when all the epitaxially deposited layers are thickened. If this produces an inconveniently large offset, this can be remedied by introducing a compensating traverse step (not shown) into the surface of the substrate upon which epitaxial growth takes place, this step registering with the inboard ends of the two stripes 19.

The laser 10 could be a Fabry-Perot type structure with one reflecting facet formed by the end facet 20 of the chip and the other facet formed by a vertical wall of a trench etched deep into the chip through the epitaxial layers between the laser 10 and the modulator 11, In this instance however it has been preferred instead to employ a distributed feedback structure to provide the requisite feedback for laser action, and to suppress reflection at the facet 20 by means of an anti-reflection layer (not shown) deposited upon this facet. Distributed feedback is provided either by etching a diffraction grating in the substrate beneath the laser before the growth of its epitaxial

layers, in which case the growth of layer 13 is omitted, or by temporarily halting the epitaxial growth after the growth of the upper waveguide layer 16, etching a diffraction grating (not shown) in the exposed surface, and then recommencing and completing the epitaxial growth process.

An optical waveguiding effect, for both the laser and the modulator, in the direction normal to the planes of the epitaxial layers is provided by the refractive index profile produced by the layer structure. A lateral waveguide effect is provided either by adopting the conventional double channel approach of a ridge waveguide heterostructure laser, or by making a buried heterostructure. Figure 1 depicts the ridge waveguide version, for which two channels 21 are etched through the capping and upper cladding layers 18 and 17 to expose the underlying upper waveguide layer 16, these channels 21 being spaced to leave a intervening rib approximately 3 μm wide. At the same time a transverse channel 22 is etched to the same depth, this transverse channel being designed to provide electrical isolation between the p-type material of the laser 10 and the p-type material of the modulator since, in use, the former will be forward biased and the latter reverse biased. For a buried heterostructure version (not illustrated) the channels are etched through the active layer and these are infilled with semi-insulating InP.

An electrically insulating layer of silica (not shown) is deposited over the surface of the epitaxially grown material, and two windows are opened in it, one to register with the rib of the laser and the other with the rib of the modulator, these ribs being defined by the two channels 21. After thinning of the substrate, metallisation contact layers (not shown) are deposited

on the top and bottom surfaces of the chip, the top metallisation layer being divided into two parts to enable separate contact with the laser and with the modulator.

In Figure 2 there is shown a set of spectral absorption characteristic curves 25a to 25d of a discrete modulator substantially identical with the modulator part of the chip of Figure 1, the curves being respectively for bias levels of 0 volts, -2 volts, -4 volts and -6 volts. At zero volts bias the absorption is seen to fall away quite rapidly with increasing wavelength on the long wavelength side of the fundamental heavy hole exciton absorption peak 26, but at increasing reverse bias levels this fall away in absorption becomes progressively less rapid. The emission wavelength of a laser having the identical layer structure is given by the vertical line 27. It is seen therefore that if the device of Figure 1 were modified to exclude the presence of the masking stripes 19, and thus provide the laser portion with a layer structure identical with that of the modulator portion, then the available depth of modulation provided by the modulator is not very great. However in the device of Figure 1 the quantum well layer thickness is not the same in the laser portion 10 as in the modulator portion 11, but is greater by about 20% in the laser portion. In consequence the emission wavelength of the laser is shifted from the position given by vertical line 27 to a position in the neighbourhood of vertical line 28. From Figure 2 it is seen that this shift in emission wavelength reduces the attenuation of the laser emission by the modulator when the modulator is in its unbiased state.

In the device of Figure 1 the quantum-well layers were made thicker in the laser portion than in

the modulator portion by virtue of the enhanced growth rate promoted between the two stripes 19, but enhanced growth rate may alternatively be promoted by the use of a laser beam directed at selected areas of the chip during epitaxial growth to enhance growth rate photochemically. A further alternative approach is to promote a diminished growth rate in the region of the modulator portion. Diminished growth rate can for instance be achieved, when employing liquid phase epitaxy, by arranging for the growth in the modulator portion to be on the top of a narrow rib, typically about 10 μm wide, while that in the laser portion is on a planar surface.

CLAIMS.

1. A monolithic semiconductor structure that includes an injection laser and a quantum-confined Stark effect optical modulator optically in tandem.

2. A monolithic semiconductor structure that includes a quantum-well laser and a quantum-confined Stark effect optical modulator optically in tandem, wherein the or each quantum-well layer of the laser is of greater thickness than the corresponding quantum-well layer of the modulator, so that when the modulator is unbiased, its fundamental exciton absorption peak is further on the short wavelength side of the laser emission wavelength than it would be if the quantum-well layers were the same thickness in both the laser and the modulator.

3. A monolithic structure as claimed in claim 2, wherein the or each quantum-well layer of the modulator is a continuation of the corresponding quantum-well layer of the laser.

4. A method of making a monolithic semiconductor structure that includes a quantum-well laser and a quantum-confined Stark effect modulator optically in tandem, wherein the quantum-well layers of both the laser and the modulator are epitaxially grown simultaneously upon a substrate whose topography provides a faster growth rate, and hence greater layer thickness, in the region employed to form the laser than in the region employed to form the modulator so that, in the completed structure when the modulator is unbiased, its fundamental exciton absorption peak is further on the short wavelength side of the laser emission wavelength than it would be if the quantum-well layers had been grown with the same layer thickness in both the laser and the modulator.

5. A method of making a monolithic semiconductor structure as claimed in claim 4, wherein the substrate topography includes, in the region employed to form the modulator, two channels defining an intervening ridge upon which the epitaxial growth rate of quantum-well layers is diminished with respect to that which occurs upon a substantially planar region.

6. A method of making a monolithic semiconductor structure as claimed in claim 4, wherein the substrate topography includes, in the region employed to form the laser two masking strips defining an intervening strip upon which the epitaxial growth rate of quantum-well layers is enhanced with respect to that which occurs upon a substantially planar region remote from masking.

Amendments to the claims have been filed as follows

CLAIMS.

1. A method of making a monolithic semiconductor structure that includes a quantum-well laser and a quantum-confined Stark effect modulator optically in tandem, wherein the quantum-well layers of both the laser and the modulator are epitaxially grown simultaneously upon a substrate whose topography provides a faster growth rate, and hence greater layer thickness, in the region employed to form the laser than in the region employed to form the modulator so that, in the completed structure when the modulator is unbiased, its fundamental exciton absorption peak is further on the short wavelength side of the laser emission wavelength than it would be if the quantum-well layers had been grown with the same layer thickness in both the laser and the modulator.

2. A method of making a monolithic semiconductor structure as claimed in claim 1, wherein the substrate topography includes, in the region employed to form the modulator, two channels defining an intervening ridge upon which the epitaxial growth rate of quantum-well layers is diminished with respect to that which occurs upon a substantially planar region.

3. A method of making a monolithic semiconductor structure as claimed in claim 1, wherein the substrate topography includes, in the region employed to form the laser two masking strips defining an intervening strip upon which the epitaxial growth rate of quantum-well layers is enhanced with respect to that which occurs upon a substantially planar region remote from masking.

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